

## CLAIMS

1           1.     A method for etching oxide on a semiconductor substrate,  
2     comprising exposing the oxide on the substrate to hydrofluoric acid vapor and  
3     water vapor in a process chamber held at temperature and pressure  
4     conditions that are controlled to form on the substrate no more than a sub-  
5     monolayer of etch reactants and products produced by the vapor as the oxide  
6     is etched by the vapor.

1           2.     The method of claim 1 wherein the semiconductor substrate  
2     comprises a silicon wafer and the oxide comprises silicon dioxide.

1           3.     The method of claim 1 wherein the temperature and pressure  
2     conditions are controlled to etch the oxide on the substrate at a rate of no  
3     more than about  
4     100 Å/minute.

1           4.     A method for cleaning a contaminant on a semiconductor  
2     substrate, comprising exposing the contaminant on the substrate to  
3     hydrofluoric acid vapor and water vapor in a process chamber held at  
4     temperature and pressure conditions that are controlled to form on the  
5     substrate no more than a sub-monolayer of reactants and products produced  
6     by the vapor as the contaminant is removed by the vapor.

1           5.     A method for removing etch residue from a metal structure on a  
2     semiconductor substrate, comprising exposing the residue to hydrofluoric acid  
3     vapor and water vapor in a process chamber held at temperature and  
4     pressure conditions that are controlled to form on the substrate no more than

5 a sub-monolayer of reactants and products produced by the vapor as the  
6 residue is removed by the vapor.

1 6. A method for cleaning a metal contact region of a semiconductor  
2 substrate, comprising exposing the metal contact region to hydrofluoric acid  
3 vapor and water vapor in a process chamber held at temperature and  
4 pressure conditions that are controlled to form on the substrate no more than  
5 ~~sub~~ a sub-monolayer of reactants and products produced by the vapor as the  
6 residue is removed by the vapor.

1 7. A method for etching oxide on a semiconductor substrate,  
2 comprising the steps of:  
3 exposing the oxide on the substrate to a stream of frozen particles; and  
4 exposing the oxide on the substrate to hydrofluoric acid vapor and  
5 water vapor in a process chamber held at temperature and pressure  
6 conditions that are controlled to form on the substrate no more than a  
7 multilayer of etch reactants and products produced by the vapor as the oxide  
8 is etched by the vapor.

1 8. A method for cleaning a contaminant on a semiconductor  
2 substrate, comprising the steps of:  
3 exposing the contaminant on the substrate to a stream of frozen  
4 particles; and  
5 exposing the contaminant on the substrate to hydrofluoric acid vapor  
6 and water vapor in a process chamber held at temperature and pressure  
7 conditions that are controlled to form on the substrate no more than a  
8 multilayer of etch reactants and products produced by the vapor as the oxide  
9 is etched by the vapor.

1           9.     The method of either of claims 7 or 8 wherein the process  
2     chamber temperature and pressure conditions are controlled to <sup>form</sup> from on the  
3     substrate no more than a saturated monolayer of etch reactants and products  
4     produced by the vapor as the oxide is etched by the vapor.

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1           10.    The method of either of claims 7 or 8 wherein the process  
2     chamber temperature and pressure conditions are controlled to <sup>form</sup> from on the  
3     substrate no more than a sub-monolayer of etch reactants and products  
4     produced by the vapor as the oxide is etched by the vapor.

1           11.    The method of either of claims 7 or 8 wherein the stream of  
2     frozen particles comprises a stream of frozen CO<sub>2</sub> particles.

1           12.    A method for etching oxide on a semiconductor substrate,  
2     comprising the steps of:  
3            producing a positive electrical charge on the oxide; and  
4            exposing the oxide on the substrate to hydrofluoric acid vapor and  
5     water vapor in a process chamber held at temperature and pressure  
6     conditions that are controlled to form on the substrate no more than a  
7     saturated monolayer of etch reactants and products produced by the vapor as  
8     the oxide is etched by the vapor.

1           13.    A method for etching oxide on a semiconductor substrate,  
2     comprising the steps of:  
3            producing a positive electrical charge on the oxide; and  
4            exposing the oxide on the substrate to hydrofluoric acid vapor and  
5     methanol vapor in a process chamber held at temperature and pressure

6 conditions that are controlled to form on the substrate no more than a  
7 saturated monolayer of etch reactants and products produced by the vapor as  
8 the oxide is etched by the vapor.

1 14. A method for etching oxide on a semiconductor substrate,  
2 comprising the steps of:  
3 producing a positive electrical charge on the oxide; and  
4 exposing the oxide on the substrate to hydrofluoric acid vapor and  
5 isopropyl alcohol vapor in a process chamber held at temperature and  
6 pressure conditions that are controlled to form on the substrate no more than  
7 a saturated monolayer of etch reactants and products produced by the vapor  
8 as the oxide is etched by the vapor.

1 15. The method of any of claims 12, 13, or 14 wherein the process  
2 chamber temperature and pressure conditions are controlled to <sup>form</sup> on the  
3 substrate no more than a sub-monolayer of etch reactants and products  
4 produced by the vapor as the oxide is etched by the vapor.

1 16. The method of any of claims 12, 13, or 14 wherein the positive  
2 electrical charge is produced on the oxide by exposure of the oxide to an  
3 electron beam.

1 17. The method of any of claims 12, 13, or 14 wherein the positive  
2 electrical charge is produced on the oxide by exposure of the oxide to  
3 ultraviolet light through a metallic screen.

1 18. The method of any of claims 12, 13, or 14 wherein the positive  
2 electrical charge is produced on the oxide by exposure of the oxide to a

3 plasma environment wherein the substrate is biased by a negative-polarity  
4 DC voltage.

1 19. A method for etching oxide on a semiconductor substrate,  
2 comprising the steps of:  
3 producing a negative electrical charge on the oxide; and  
4 exposing the oxide on the substrate to hydrofluoric acid vapor and  
5 water vapor in a process chamber held at temperature and pressure  
6 conditions that are controlled to form on the substrate no more than a  
7 multilayer of etch reactants and products produced by the vapor as the oxide  
8 is etched by the vapor.

1 20. The method of claim 19 wherein the negative electrical charge is  
2 produced on the oxide by exposure of the oxide to a plasma environment  
3 wherein the wherein the substrate is biased by a RF voltage.

1 21. The method of claim 19 wherein the negative electrical charge is  
2 produced on the oxide by exposure of the oxide to a plasma environment  
3 wherein the substrate is biased by a positive-polarity DC voltage.

1 22. A method for etching oxide on a semiconductor substrate,  
2 comprising the steps of:  
3 releasing electrical charge from the oxide by exposing the oxide on the  
4 substrate to a stream of frozen particles, the substrate temperature  
5 remaining uncontrolled during the exposure; and  
6 exposing the oxide on the substrate to hydrofluoric acid vapor and  
7 water vapor in a process chamber held at temperature and pressure  
8 conditions that are controlled to form on the substrate no more than a

9        multilayer of etch reactants and products produced by the vapor as the oxide  
10       is etched by the vapor.

1                23.    The method of claim 22 wherein the process chamber  
2        temperature and pressure conditions are controlled to ~~from~~ on the substrate  
3        no more than a saturated monolayer of etch reactants and products produced  
4        by the vapor as the oxide is etched by the vapor.

1                24.    The method of claim 20 wherein the process chamber  
2        temperature and pressure conditions are controlled to ~~from~~ <sup>form</sup> on the substrate  
3        no more than a sub-monolayer of etch reactants and products produced by the  
4        vapor as the oxide is etched by the vapor.